In Defense of Science

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It will not surprise you that I rise in defense of science. Only yesterday, no such defense seemed required. The tinkering, inventor folk-heroes of yesterday – the Wrights, Morse, Bell, Edison, Ford – had been replaced in part by a new set of household names – Einstein, Oppenheimer, Watson, and Crick. Science-based technology was accepted as a cornucopia from which only good could flow and it seemed that Toynbee had indeed expressed the modern credo, "Our age will be remembered because it is the first generation in which mankind dared to believe it practical to make the benefits of civilization available to the whole human race."

Suddenly, we are confronted with the vision of science and technology as a modern Janus – a two-faced god. We are told that when we consider atomic energy we should envision apocalyptic nuclear extermination, radioactive wastes, and harmful genetic mutations; that heavy industry equates to pollution of rivers and streams; that fertilizers, insecticides, and pesticides developed for agricultural productivity bring contamination of our food and of earth itslef; that mass-produced personal transportation is the major source of air pollution; that the educational potential of television has been transmuted into the idiot-box of crass commercial materialism; that the wonders of the new pharmacopoeia evoke only visions of malformed infants; that the triumphal selection of foodstuffs in every supermarket conveys possible carcinogens and mutagens; that microminiaturization of electronics connotes loss of privacy and a depersonalized machine culture; that our growing understanding of the human brain and of genetic mechanisms can bring tyranny; that sanitation and medicine bring overpopulation and human degradation; that steroid contraceptives promote licentiousness and destruction of the family.

These views were brassily stated by Paul Goodman, "Inevitably, given the actual disasters that scientific technology has produced, superstitious respect for the wizards has been tinged with a lust to tear them limb from limb." And so it seems that "Do not fold, spindle or mutilate" refers not to IBM cards but to human beings.

More reasonably, according to Harwood, "Science and technology must not be rampant, irrespressible forces to which man must meekly submit. The challenge is not where technology is blindly leading us, but how can science and technology help get us where we want to go?" He asks, "Through which code of morals can society exploit and control science and technology, not only to assure physical survival and material comforts, but to assure the survival of human values and the more equitable betterment of mankind. Does a basis for such moral values reside intrinsically within the practice of science itself?"

Ethics and Morals

No society can survive without value standards and an ethical system, yet thoughtful scientists consider that no existing system, no revealed religion, no 19th Century rationalistic philosophy, neither Marxism nor existentialism can sustain man in the modern world. Jacques Monod's contention is that older value systems wither into absurdity when confronted by that science which reaches truth by confrontation of logic with experience. But Monod offers no substitute ethic.

From the personal standpoint of the scientist, these matters were summarized in

[1]The 1971 Joseph Henry Lecture, presented at the 1673rd meeting of the Philosophical Society of Washington, Washington, D.C. on May 14, 1971.

part by Warren Weaver, "Science is not technology, it is not gadgetry, it is not some mysterious cult, it is not a great mechnical monster; science is an adventure of the human spirit. It is an essentially anarchistic enterprise stimulated largely by curiosity, served largely by disciplined imagination and based largely on faith in the reasonableness, order and beauty of the universe of which man is part."

This vision is amplified in a remarkable recent book entitled *Behind Appearance*, a study of the relations between painting and the natural sciences in this century by the distinguished geneticist C.H. Waddington. He states that his book ". . . is not intended to be a general survey of the science-culture chasm, but is a moderately detailed reconnaissance of one of the areas in which the chasm turns out to be quite a narrow, shallow cleft across which it is easy to step," as scientists would like to believe.

Science is more than just a record of observations and empirical fact; it is knowledge organized in such fashion as to permit insight into all natural phenomena and forces, so that, from the relatedness of facts it creates unity out of diversity. It is this recognition of connections – where none appeared to exist before – that is the essence of scientific creativity. Although the requirements of precision and logic, the necessity of conforming to facts, the methodology of testing of concepts and ideas, create the impression of scientific activity as an impersonal exercise, nothing could be further from the truth. Science is a truly human experience, and it is the pleasure and excitement of personal involvement which underlies scientific creativity. But that does not constitute an ethos.

A scientific ethic can be described, albeit in retrospect. It would include personal independence in observation and hypothesis, regardless of established dogma; free inquiry and dissent but at least temporary acceptance of the common fund of accepted knowledge; free communication of both observation and interpretation; open-minded willingness to consider revision of older doctrine. To be sure, as Alvin Weinberg said, "In all honesty, I have never once seen a scientist doing something differently in his scientific work because of some relevant stricture or canon from the philosophy of science." Despite the occasional caustic assertion that scientists treat the philosophy of science with exasperated contempt, that philosphy *is* useful for the scientist; it makes him aware of his implicit assumptions even if it is not a tool to be used explicitly like the calculus or programming. In this sense, science is enriched by the philosophy of science itself.

And, there must also be explicit recognition that, on occasion, the ends for which science drives will be judged by the means used to reach them – witness the universal rejection of the experimentation with human subjects conducted by Nazi scientists.

This ethic derives from the necessities of science itself; no alternative is available as a means to objective knowledge. But, restated, the values so held are also those of our civilization: dignity, freedom, justice, democracy are cherished moral values, so much a part of the the scientific ethic that Bronowski surmised that if such values had not previously existed, the scientific community would have had to invent them.

The Attack on Science

Current concern for science, then, lies with its interaction with society through technology. Scientists generally have agreed with Glenn Seaborg that, "Knowledge is born without moral properties. It is man who applies it according to his acquired pattern of behavior. Man, not knowledge, is the cause of violence." But that is too facile. If it be true that "science is what scientists do," then the latter cannot escape the responsibility to make known the conceivable consequences of their newly gained understanding when they have the foresight and wisdom to so do. That is why after Hiroshima, Robert Oppenheimer said that, "For the first time, the scientist has known sin."

1. A perpetual problem is public failure to distinguish between science and misuse of the technology it makes possible, whether

that be seen as unpredicted effects on population, the environment, or the arms race.

2. Other forces, more subtle, are at work as well. Once again some proclaim that most of the important work of science in revealing the nature of the universe including man himself has already been done. Such predictions have been made in the past – and belied by subsequent history. There is little reason to think otherwise today. Certainly no biologist seeking to understand man as an organism or sociologist seeking to understand man the social creature, no astronomer concerned with cosmology, no theoretical physicist could accept such a view.

3. It is difficult to assess the public impact of the rise of those cults which emphasize the affective aspects of human experience rather than the cognitive and analytical. How disconcerting that our society supports at least 30 times as many astrologers as astronomers! Nor can we estimate the future impact of those movements which would diminish public esteem of the components of our high culture, romanticising the underprivileged and promoting the egalitarian, when science is surely the activity of a particular elite. I no more understand "science for the people" than I know what is meant by the "age of Aquarius." But when we are portrayed as the "mad scientists" of television or are seen as individuals who may speak mathematics or chemistry, who use English itself in strange ways, the xenophobia inherent in every culture generates distrust by reflex.

4. The scientist may find deep satisfaction in statements like that of Sir Brian Flowers', "Science, like the arts, gives expression to the innermost yearnings of the human spirit and thereby enriches our lives. It changes profoundly our comprehension of the world around us and of our place in it." But that satisfaction is shared by a very small fraction of our population. The usual conservatism of social systems retreats from the vastness and hostility of the cosmos revealed by modern astronomy, from the suggestion that, one day, man's brain will be totally comprehensible in physical terms; from the allegation that, biologically speaking, man is more closely related to the chimpanzee than is the horse to the donkey. It is unlikely that such thoughts would lead to declining public support for science or diminished numbers of students seeking scientific careers, but they do contribute to an increasingly unfavorable climate for public consideration of the claims of science on the public purse, exacerbating the current malaise of science.

5. And, of course, there is the tiresome complaint that fundamental research is becoming progressively more abstract and irrelevant to society. Strangely, those who make this statement also request unprecedented control of science for the preservation of the good life, in which case, I fail to see why irrelevant activities need rigid control. Patently, those who make such claims fail to appreciate the process by which relevant innovation arises from the continuing interplay between fundamental and applied research, and fail to appreciate the long lead time – no less than a decade – for translation of scientific findings into societally useful technology.

6. How much we have accomplished since World War II! That now we may find it wanting reflects not failure of science or adaptation to technology, but a yet more rapid alteration of our perceived goals, the societal equivalent of the well-known "floating aspiration level" of individual humans. In generating new technology one has little choice but to rely on the existing fund of knowledge. Many young people find themselves dissatisfied; they are, it seems, setting ill-formed, vague new goals. And if these are to be met we shall surely require yet more knowledge, but as yet unspecified. If immediately perceived social goals be utilized as the measure of "relevance", then, in all probability, the intellectual community will be behaving as do generals when they "prepare for the last war." It is precisely because, a decade hence, our goals will again have changed that nothing can be more relevant than undirected fundamental research which simply must occupy a substantial fraction of the scientific community if we are to be positioned for that tomorrow.

7. A small but vocal tide of concern suggests that some aspects of science are best left unexplored, a movement which has two aspects. To one we have already referred, the chronic resistance to the intrusion of new knowledge which might substantially alter previously held views. This was well expressed by Eddington in his *The Nature of the Physical World*, "We are drawing near to the great question whether there is any domain of activity – of life, of consciousness, of deity, which will not be engulfed by the advance of exact science, and our apprehension is not directed against the particular entities of physics, but against all entities of the category to which exact science can apply. For exact science invokes, or has seemed to invoke, the type of law, inevitable and soulless, against which the human spirit rebels. If science finally declares that man is no more than a fortuitous concourse of atoms, that blow will not be softened by the explanation that the atoms in question are the Mendelian unit characters (we now call these genes) and not the material atoms of the chemist."

The other aspect of this problem has emerged in public repugnance at the possibilities of "genetic engineering," including production of multiple copies of a single individual by cloning. But, book-burning was ever evil; resistance to the advance of science at its exciting frontiers is its modern equivalent and not only delays progress, it erodes the moral fiber of civilization, a precious, fragile veneer over our animal state.

It will, of course, remain for society, collectively, to manage the manner in which the information so gained is to be used. Scientists, no less than others, are repelled by the image of a world populated by multiple copies of idiot laborers, football players or soldiers, or even of Einstein or Mozart for that matter. Nor have we any taste for mass manipulation of the population by the utilization of mind-altering drugs. But society must surely protect the right of informed and understanding scientists to undertake those experiments by which genuine information and understanding might be acquired, just as society must subsequently determine how such knowledge shall be employed.

8. There is growing concern for the history of cooperation between the scientific community and the military. Pondering nuclear, biological and chemical weapons, those espousing the extreme view could argue that since new knowledge is most easily available to those with political and economic power, acquisition of new knowledge must inevitably lead to further concentration of that power and, thus, must be inherently evil. Those who so hold, according to Harvey Brooks, have replaced the adage "The truth shall make you free" with the slogan "Beware of the truth, for it can be used to enslave you."

Another aspect of the relationship between the military and the scientific community has had insufficient attention. For well known historical reasons, the earliest Federal sponsor of scientific research on the current scale was the Department of Defense. That support remained essentially unchallenged until Senator Mansfield pressed for support, by the military, of only those scientific projects which can be shown to have an immediate relationship to military needs. Those closest to this problem believe that it would be tragic if rigid implementation of that philosophy were to result in a clear separation of the military from the very best of the academic technical community. They believe, as do I, that while we require a Defense Department, as we do, let it be competent.

On the other hand, we may have already paid some price for the device, understood by all concerned, whereby support of a great deal of fundamental research has been underwritten by the Defense Department with little or no reference to the immediacy of its application. This has advanced many areas of science, notably solid state physics, while the funds so used were probably made available with no reduction in the funds which otherwise might have been made available to the Defense Department. The cause of progress in science and its applications was certainly served thereby.

What is not measurable is the influence this history may have had on the attitudes of

an entire generation of physical scientists, who albeit all unwittingly, cannot help but regard the policies and programs of the Defense Department somewhat more sympathetically than might otherwise have been the case. The consequences of this situation are uncertain. But one may certainly raise the question as to whether that element of the scientific community might have challenged the ABM system, the SST, or even intervention in South Vietnam earlier than they did.

9. This may be translated into the frequently debated question of what fraction of the national research endeavor should be funded through a central research authority – as in Britain – and what fraction through mission agencies. I insist that a substantial protion of the effort, even on campus, should be funded through the mission agencies both so as to enhance their mission capability and assure awareness of agency problems among the external technical community. But I also believe that we have overdone this and that we should look to the day when an adequately funded NSF – or its equivalent – provides about one-half of the federal support of basic research.

10. One other lesson may be drawn from this history. The magnitude of funding of academic science from a variety of agencies has delayed the day when the federal government must accept responsibility for the fiscal stabilization of the universities. This responsibility is still being met in part by local "bootlegging" of Federal funds appropriated for research, thereby further delaying the long overdue stabilization of the financial base for both private and state institutions of higher education.

11. It is frequently stated that if science is to find support from the public exchequer at a level greater than that which it would receive as a purely cultural endeavor, there is a continuing burden to demonstrate its relationship to societal need. As we have seen, however, that relevance really is, and should be, to as yet unperceived need; moreover, as Don Price notes, when science is thus placed in the public arena, it becomes exposed and vulnerable.

Those who would further the cause of science must understand that, whatever the past, however glorious and uplifting some of us may find the intellectual edifice of science, it can be protected against attack only with the understanding that, whereas science cannot determine the values which direct political choices, science cannot be totally irrelevant to them. This understanding must be particularly clear to those encharged with support of the social sciences which are, as yet, institutionally weaker than are the natural sciences. I become particularly alarmed when the cry for relevance, by students and others, threatens to reorient universities, the respositories of disciplinary competence, so that they shall become multidisciplinary, problem-solving organizations. The disciplinary frontiers *are* the frontiers of our civilization. Only when they are vigorously explored will our problem-solving capability be assured – on campus or off.

12. Increasingly disconcerting is the loss of faith in the belief that science is the principal instrument for alleviating the condition of man. Allocation of all possible resources to the amelioration of domestic and international problems is demanded, as if we already possessed all the information and understanding required. Such sounds emanate from every campus and are occasionally reflected by those in the political arena who would pander to such sentiment. In the face of these pressures, it appears ever more necessary to educate those in authority to the social values of undirected fundamental research, an education which usually consists of a recital of anecdotes. That would be aminor problem were it not for the fact that, to compensate, scientists, who should know better, succumb to the temptation to over-promise. Witness the behavior of those who have recently indicated that only sufficient funding stands between us and definitive therapy of neoplastic diseases.

13. In any case, let us not exaggerate the plight of American science. Funding for basic research has declined from fiscal year 1967 by perhaps 20% in constant dollars. Since some laboratories may have been rather generously funded, and there may

even have been some marginal investigators whose loss from the system is small loss to society, of itself that decrement might not have been too serious. Research in many disciplines proceeds with great vigor and sense of accomplishment.

The funding difficulties so painfully perceived in many research laboratories stem rather from the fact that this system, with earlier Federal encouragement, has been operating so as to double the available scientific population in each decade. And the pipelines are still full; graduate student enrollments have not yet suffered significantly. But declining undergraduate enrollments in science appear more serious; we shall badly need many of these young men and women one day, although it would be well to reduce annual output somewhat. Should that not prove true, should there not be appropriate jobs for them, our country will have fallen off the track of true progress. Much as policy for fundamental research must admit that it is directed toward the requirements of society a decade or more hence, so too, must our policies for support of graduate education – which must not be blinded by transient episodes such as the current, temporary I trust, technological unemployment, particularly on our West Coast.

We are now living through a transition phase from the time in which all major decisions affecting our national life were made in a market economy to a time when, inevitably, all such decisions will be taken in the public sector. That we are woefully unskilled in this art is evident in the disingenuous exclamations of governmental dismay when wholesale unemployment of technically trained individuals resulted from sharply decreased Federal funding of applied research and development in the aerospace industry, when, patently, the government itself was known to be the only customer. We sadly lack a national vision or will, much less plan, as to how we shall address our national technical capabilities to the battery of discernible problems, domestic and international, which demand technical solutions. My subsequent remarks will attempt to illustrate a few of these problems.

Health Care

I consider myself extraordinarily privileged to have witnessed at first hand the glorious development of biochemistry. But I also recognize how much more there is to be learned than is yet known. And that is precisely the point. One can fashion an impressive list of all those diseases for which research has already provided definitive, therapeutic, or preventive measures. In the main, these are nutritional deficiencies, infectious processes, and endocrine disorders. The cost of the earlier research and the current costs of dealing with these diseases are trivial as compared with the costs when each was a major affliction of mankind.

In contrast, the diseases which currently take serious toll of mankind are those which are now understood insufficiently to offer a basis for definitive prevention or therapy. And it is the less than satisfactory, terribly costly palliative management of these diseases, utilizing what Ivan Bennett has termed "halfway medical technology," which is what one means by the "health care" for which the country clamors. How comparatively trivial are the costs of research!

But how long and difficult the task is. Is it not remarkable that, amid the cries of irrelevance, no attention has been paid to the fact that 1970 offered proof that it was possible to abolish a once devastating disease? For the first time in recorded history, last year, not a single case of smallpox was reported in 20 African nations receiving U.S. aid in a WHO-organized eradication program. That event may go unnoticed in political history, but in the real history of mankind it represents one of man's truly great triumphs over his ever-hostile environment.

The Environment

The fever pitch of national, indeed international, concern for the environment is a phenomenon which future historians must evaluate in the perspective of man's occupancy of our planet. The universal intensity of these feelings probably arises from the fact that, at some time, each of us feels

threatened by environmental disaster or offended by unsightly cities or landscapes. Yet, even now, man's effect on the general environment is trivial as compared to that of natural forces.

Consider the effects of climate, erosion of continental surfaces by rivers and streams, transpiration of vegetation, the emanation of the terpenes from pine and cedar trees which long ago led man to name regions of the Appalachians as the Blue Ridge and the Smokies. Consider the lovely landscapes of England which were fashioned in the last several centuries from primeval forests and exist by virtue of the otherwise abominable English climate. Or the magnificently tilled hillsides of France, Italy, and Japan, all of which were fashioned by the hand of man. Or the great, rich loam of our own prairies – the consequence of centuries in which the Indians burned over the native vegetation as a means to drive the buffalo; to say nothing of earthquakes, tidal waves, or landslides.

Man and nature have ever been altering the total environment. Yet our tragically blighted cities are cleaner and healthier than were urban agglomerates anywhere in the world until the middle of the last century. We have not suddenly begun to alter the environment. Our justifiable concern arises from the logarithmic concatenation of our ever-increasing numbers, our productive heavy industry, coupled with increasingly sensitive chemical analytical procedures which permit detection of contaminants in minute amounts, some of which – like the mercury in the swordfish – have probably been there all these years.

Many current problems can be handled reasonably well with available off-the-shelf technology, as it were. But we have not yet established the social mechanisms whereby to bear the costs or agreed on what we shall forego so as to do so. My plea is that we do not, out of a combination of emotional zeal and ecological ignorance, romanticizing "good old days" that never were, hastily substitute environmental tragedy for existing environmental deterioration. Let us not replace known devils by insufficiently understood, unknown devils, as when phosphate in detergents was replaced by inadequately evaluated NTA, or caustic soda, or when, tragically, highly toxic parathion was substituted in some instances for too stable, but relatively innocuous DDT. The brute fact is that ecology is, as yet, a young, little developed science which requires much nourishment before it can adequately serve society.

It seems strangely difficult to order national priorities. How remarkable that we should weigh air pollution from automobile tailpipes more heavily than the annual carnage on our highways – 56,000 deaths and hundreds of thousands of injured last year – or that we so easily ignore the 15 tons of TNT equivalent for each man, woman and child on the face of the earth now reposing in the nuclear tips of the world's arsenals.

Perhaps, however, that is the solution. Were we to galvanize the governments of the world into an international effort to reverse the deterioration of the planetary environment, utilizing funds released by a moratorium in the arms race, we might also contribute to the cause of a stable peace. Surely the ultimate environmental catastrophe is nuclear warfare.

Energy and Natural Resources

This country does not face an immediate natural resource crisis. Although coal mining is currently a distressed industry and we depend upon imports for 25 out of 32 strategic minerals, we have no current problems in satisfying our wants in these regards. But the analyses of this problem which I see invariably strike me as being incredibly short-sighted in that they fail to anticipate the day when currently less developed countries will want these minerals for their own purposes. So-called "long-term" projections extend to the year 2000 or even 2100 – when I expect mankind to be walking the earth in the year 200,000. On that time scale, without exquisitely careful international planning, there may be insufficient quantities of any natural resource other than water and oxygen.

Is it not almost sinful that we burn petroleum as a source of energy, thereby

denying our progeny of this unique raw material for chemical industry? Can mankind not become wise enough to husband this unique resource before its exhaustion? And yet energy production and utilization lie at the heart of our civilization. Each of us cherishes his personal transporation, and although we shall surely manage to reduce the air pollution engendered by the internal combustion engine, no truly acceptable substitute for petroleum as a fuel source for an equivalent mode of personal transporation has yet become evident.

Equally perplexing is our attitude with respect to large-scale energy production. Electric power drives our civilization. Nuclear power plants, whether of the current variety, the breeder reactors under development, or the ultimate of controlled fusion must soon become absolutely essential to our way of life since return to more primitive times is really unacceptable.

In part, this is because we are not really a consuming civilization, but a processing one, generating vast quantities of waste which demand disposal. Possibly, with sufficient ingenuity we shall devise means for recycling much of it. But that will, necessarily, require expenditure of yet more energy. Thermodynamics permits no way out of this dilemma. Hence, early resolution of the conflict between the proponents of energy production and the environmentalists must soon occur. This difficult political decision must rest on an adequate, comprehensive, objective analysis of these problems, but none is yet available.

My point, then, is that the requirements and opportunities for research germane to this assemblage of environmental, transportation, energy use, and wastedisposal problems could profitably utilize the research attention of a great battery of scientific talent, but we have not yet agreed to do so, much less organized to undertake these tasks. Industry can do much, but leadership rests with the government.

Population

Our population problems do not arise out of concern for our ability to feed ourselves. They will arise, in part, from our growing inability to provide useful employment to many because the others will be so productive and from the impact of our very affluence on the environment and supply of raw materials. In the economically underdeveloped world, population growth is *the* deterrent to improvement in the quality of life. In a sense, it is almost sad to realize that, thanks to the "green revolution", Malthus was wrong. We shall almost certainly be able to feed a world population which is intolerably large by any other criteria. But surely starving people to death cannot be the solution!

Here again, research has scarcely begun. The first generation of mechanical and chemical means of contraception, remarkably successful as they have proved, will certainly not suffice. We yet require simpler, cheaper, safer, more reliable methods, and these can derive only from better understanding of reproductive physiology. Even now, however, lack of acceptable social mechanisms to ensure their utilization is a principal impediment to population control. Nor should it be thought that the task of agricultural research is complete. On the contrary, it has no end and its very successes bring yet more problems.

Thus we stand at a strange crossroad. The pattern and quality of American life is largely the product of past research. In some of the very areas where, in the past, we have been most successful, the direction of future efforts is now in question. To be sure, some of the most exciting visions in the history of man, particularly those of molecular biology, have as yet found little application. Whereas science is most capable when studying the infinitely large or the infinitesimally small, man's most serious problems lie in the as yet insufficiently comprehended range between. Physiology, psychology, developmental biology, soiciology, and ecology, *inter alia*, are as yet too primitive for applied societal purposes, while the problems to which these disciplines might contribute grow ever more intense. And yet the research effort is said to be irrelevant.

The Planet as a System

The view of earth from space brought home how small our planet really is, and gave stimulus to what is becoming a new discipline – systems analysis of the entire world biosphere. Such studies seek to understand, by computer modelling, utilizing as many parameters as can usefully be invoked, what the longer-term history of our planet may be. After adopting a set of arbitrary assumptions, models are constructed indicating future consequences of the sustained growth or decline of the world population, of the food supply, the energy supply, waste accumulation, etc. Sadly, these models indicate that, unless man changes the course of events, a cataclysm is in the offing sometime in the next century. This discipline is in its infancy, and it is hoped that it will yet mature sufficiently to become a useful guide to political action, perhaps to force adoption of a true world government. Those so engaged have assured themselves that we really do live in a period of sharp transition between the past and the future, in the sense that decisions taken in the next few years may make for irrevocable commitments concerning the future of mankind.

Peccei summarized it thus: "... the responsibility of controlling technology and through it of regulating the ecosystem itself, now rests on man ... He must now take upon himself functions in the cycle of life which up to now were reverently considered to be the prerogative of nature or providence, and left to their inscrutable designs. The physical world and the biosphere are now so pervasively interfered with by man's actions that he has no other alternative but to accept the responsibility of being, himself, the enlightened manager of his terrestrial kingdom." Or, according to Julian Huxley, "Man's role, whether he wants it or not, is to be the leader of the evolutionary process on earth and his job is to buide and direct it in the general direction of improvement."

The Future of Man

The brain of Cromagnon man, or certainly *Homo erectus*, was about as fully developed as that of *Homo sapiens*. He lived in small, organized groups with established mores, used primitive tools found in nature, and communicated orally with his fellows. Subsequent stages are largely hidden, but it is considered that organized societies, toolmaking, communication, agriculture, and animal husbandry developed in parallel, requiring little or no change in man's physical brain.

Man's aggressive behavior, inherited from these ancestral froms, has been evident ever since as slavery, serfdom, the harsh inhumanities of the industrial revolution, exploitation of less developed colonial nations, current inability truly to guarantee a stable peace, even the 800 incidents of bombing in the United States last year. It is not clear to what extent aggression is transmitted genetically or culturally, and, unfortunately, there is suspicion that attempts to eliminate this characteristic might also eliminate other forms of social drive, aspiration, and creativity.

In any case, until very recently, human life was interwoven with the biotic communities of which human societies formed a small part. Man, like other species, survived by accommodating himself to natural surroundings. The changes which began with the dawn of agriculture have been completed only in our own time.

But what if we make it? Suppose man does become successful manager of the earth's ecology, the species that determines where and in what numbers all other species may also survive? If our research is successful and we learn to control the planet's climate, to conserve and recycle natural resources, to minimize disease, to provide energy without hazard, and to provide an ample food supply so that humanity around the globe lives in dignity – then what? Will man evolve further, and if so, in what direction?

We have already unwittingly altered the character of the gene pool. By our actions, individuals afflicted with diabetes, phenylketonuria, and galactosemia, for example, now survive to spread their deleterious genes through the population, the forces of natural selection having been removed. Surely our

progeny will be too rational to permit further deterioration of the gene pool. Fortunately, the ability to detect a growing number of undesirable genes, in early uterine life, is rapidly improving. Such information is valueless without a commitment to abortion. I hope that our successors will find such decisions less painful than do we.

The press abounds with emotional discussions of what is called "genetic engineering." This possibility can only materialize by virtue of an enormous effort, and there is certainly no early prospect for such measures. The avowed purpose of such research is abolition of the perhaps surprisingly long list of genetically transmitted disorders. Alternatively, deletion from the human stock of undesirable genes could be approached by eugenic breeding procedures over a great many generations. Somewhat more rapid would be the use of preserved sperm banks. Whether future generations will find these procedures, or cloning, acceptable if they prove practicable is unclear; ours surely would not.

In any case, at best, these procedures would permit a population of individuals free of the extraordinarily long list of genetically transmitted disorders. Adaptation of man to the environment seems unlikely to give direction to further evolution, since man can make the environment adapt to him. But if, one day, man could truly direct his own evolution, in what direction should he guide it? What should future man be like?

Clearly, I can have no real answer to that question. But I can ask whether future man is already here. All readers of science fiction know that he should have an expanded brain with enhanced intellectual powers, probably on a diminished torso which would make less demand on the environment. Well, does *Homo sapiens* plus Computer equal *Homo supersapiens*? It is almost vulgar to think of the computer as an electrical analog of the brain, but the combination of man plus computer could well be regarded as a single organism. Computers have enormously added to productivity in the economic sense, have permitted management of vast quantities of information, heroic "number crunching", and new capabilities are imagined and employed daily. The computer not only provides an ancillary information processing system, it is a mirror to one's own mind. In learning how to converse with a computer, much is revealed about man's own thought processes. Whether some future generation of computer will itself experience affect or emotion is unpredictable. But even today, in attempting to understand rigorous thought within an emotional context much is gained.

We have no experience with adult representatives of *Homo sapiens* who have developed from childhood and lived out their lives with constant access to a computer. What would such a creature be like; It is moot whether he would be happier, whatever that means, but he would surely have vastly increased intellectual capabilities, quite possibly capabilities of which we have not yet dreamed. In that sense, he could be, in effect, a new biological species.

After the victory at El Alemein, Winston Churchill said, "This is not the end; it is not even the beginning of the end, but perhaps it is the end of the beginning." Hopefully, man himself has come to the end of the beginning. If we are fortunate and wise, science may yet be the means to set man free.